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TRITIUM

Darlington TRF

Ontario Hydro's Darlington Tritium Removal Facility (TRF) resumed operation on June 12 after replacement of piping and components in the cryogenic tritium processing systems.

Operations since the June 12 restart had yielded about 7 million curies of tritium by September 16, through the processing of 620 megagrams of tritiated heavy water at an average tritium concentration of 12 curies per kilogram. The refurbishing operations which ended on June 12 involved cutting and replacing components and pipework which had processed high concentration tritium, and were thus heavily contaminated on their inner surfaces. Procedures for decontaminating, cutting and welding tritium-contaminated pipework were developed and safely implemented by Ontario Hydro, with negligible tritium uptakes by personnel.

More information: Kam Wong, CFFTP (see Contact Data).

UNIVERSITIES

Deuterium Diffusivity in Beryllium

In early summer, McMaster University published new experimental data on the diffusivity of deuterium in beryllium metal.

Accurate data on hydrogen isotope behaviour in beryllium is important to fusion reactor designers, since beryllium is attracting interest as a fusion reactor first wall material and as a neutron multiplier in tritium breeder blankets. Diffusivity values would affect the rate of tritium release from the breeder blanket structure at operating temperatures, and so affect the rate of tritium buildup in the structure.

Diffusivity values previously reported in the literature differ by orders of magnitude. The values found in the McMaster experiments are in the upper part of the range of published values. Bulk diffusivity was measured for two grades of beryllium from Degussa AG: Extra grade (99.8 % Be) and High Grade (99.0 % Be).

The experimental data from McMaster can be fitted by the following equations:

High grade beryllium (99.0 % Be):
$D = 8.0 \times 10^{-9} \exp(-35.1/RT)\ m^2/s$

Extra grade beryllium (99.8 % Be):
$D = 6.7 \times 10^{-9} \exp(-28.4/RT)\ m^2/s$

[R is the gas constant, 8.134 x 10^{-3} kJ/mol.K, and T is temperature in degrees Kelvin.]

Deuterium permeation through beryllium wafers was measured over the temperature range 620 - 775 K, using a gas-driven permeation technique, with deuterium pressures from 5 x 10^3 to 1.3 x 10^4 Pa. A multilayer permeation model was used to derive bulk diffusivity values, so as to eliminate the effects of the beryllium's surface oxide layer, which was found to be 21 angströms thick using Rutherford backscattering techniques.

The work, supported by CFFTP, was done by a team led by Prof. Dave Thompson of McMaster University's Department of Metallurgy and Materials Science. The McMaster team plans to measure the diffusivity of hydrogen in beryllium implanted with helium atoms.

Further information from Paul Gierszewski, CFFTP (416) 855-4717 or Dave Thompson at McMaster University (416) 525-9140 ext. 4932.

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We regret that some of the pages in this report may not be up to the proper legibility standards, even though the best possible copy was used for scanning

Fusion Studies at INRS-Énergie

Institut national de la recherche scientifique.
Varennes, Québec.

The research institute INRS-Énergie has an extensive fusion studies program. INRS-Énergie is a graduate institute of Université du Québec, and has a specific mandate to train fusion scientists. INRS-Énergie is a partner in Centre canadien de fusion magnétique (CCFM), and is closely involved in operations and experiments on Tokamak de Varennes which is located at CCFM.

Fusion work by INRS-Énergie has three parts:

- Magnetic confinement studies at INRS-Énergie.
- Tokamak de Varennes operations and experiments.
- Inertial Confinement studies.

This article outlines INRS-Énergie fusion activities in magnetic confinement. Inertial confinement work will be described in a future issue of FusionCanada.

Magnetic Confinement Studies at INRS-Énergie chiefly consist of:

- Development and scientific exploitation of plasma diagnostics.
- Materials Research and ion-solid interactions studies.
- Theoretical studies.

INRS-Énergie takes a special interest in studying the tokamak plasma edge and plasma-wall interactions. Prof. Barry Stansfield is coordinator of magnetic confinement studies at INRS-Énergie, and is also coordinator of the Plasma-Wall group at CCFM.

Prof. Fernand Rheault, Director of INRS-Énergie: *"We have a mandate to train fusion scientists. INRS-Énergie will welcome enquiries from Canadian and foreign students wishing to pursue graduate studies in fusion."*

The majority of the 44 people in the Magnetic Confinement group have integral roles in operations and experimentation on Tokamak de Varennes. For example, Prof. Brian Gregory of INRS-Énergie is Director of Research for CCFM, and Prof. Jean-Marc Larsen is supervisor of control and data acquisition systems for Tokamak de Varennes. There are 21 researchers, 10 technicians and 13 graduate students in the group. The basic studies conducted at INRS-Énergie complement the experimental programs on Tokamak de Varennes.

Diagnostic instrumentation

This area is a significant part of magnetic confinement work. Of the present 36 sets of diagnostic instrumentation on Tokamak de Varennes, 22 were conceived, designed, manufactured and commissioned by INRS-Énergie. Interpretation and publication of experimental data from diagnostics carries a high priority. There follow a few examples of INRS-Énergie diagnostics projects.

Ultraviolet (UV) radiation analysis. Analysis of UV radiation from plasma impurities yields data on transport coefficients and concentrations of light impurities. A recent surprise was the discovery that the plasma edge strongly screens the plasma core against penetration by neon injected at the edge. A multichannel UV detector is being developed for measuring ion temperature from Doppler broadening of the spectral lines.

Laser injection of impurities. INRS-Énergie operates, on Tokamak de Varennes, a refined version of the laser ablation impurity injector originally built by Jim Castracane. It is used for measuring the transport of impurity ions in the core plasma, and in the divertor chambers of Tokamak de Varennes. Impurity atoms such as aluminum and silicon (not normally found in plasmas) are ablated from laser targets mounted inside the Tokamak vessel. Other instruments monitor radiation from these specific ions on their trajectories in the plasma. Using the same laser injector, another INRS-Énergie diagnostic monitors lithium and carbon radiations to measure electron temperature and density profiles in the plasma edge.

Plasma-Wall Interactions. Good progress in understanding plasma-wall interaction processes has been made with relatively simple diagnostics, including fast vacuum gauges and fast mass spectrometers analyzing tokamak gas composition. A surface analysis station allows sample coupons to be placed in the vacuum vessel at a position equivalent to the chamber wall. Exposed coupons can be removed for analysis while the tokamak vessel is under operational high vacuum.

Visible Spectroscopy. Several visible light spectroscopy diagnostics have been implemented. Measurements include:

- effective ion charge Z_{eff} from visible bremsstrahlung radiation.
- poloidal and toroidal distributions of hydrogen radiation.
- radiation from light impurities, by single chord measurements using telescopes and multichord measurements using TV cameras, recorded on video tape for later image analysis.

Langmuir probes. These apparently simple electrode probes yield information on the radial variations in plasma density, temperature, potential and flow velocity in the plasma edge. Recent work suggests that plasma flow velocity in the outer plasma edge can have a much larger poloidal component than previously suspected. An advanced, twelve-electrode fast-scanning Langmuir probe, GUNDESTRUP, is being developed to improve capability in mapping plasma edge flow velocity vectors.

Test Limiter. INRS-Énergie developed the test limiter used to position replaceable limiter heads, carrying experimental materials, in the plasma edge for materials testing. A technique was developed for estimating density and temperature in the edge plasma contacting the limiter head, by measuring visible radiation from titanium atoms sputtered from TiC-coated limiter heads. In future experiments, gas will be injected through the test limiter to measure particle transport in the edge plasma.

Neutral beam injector. INRS-Énergie is developing a neutral beam injector diagnostic for mapping spatial distribution of impurities and measuring local current density. Light emitted in charge exchange processes involving injected neutral helium atoms, and impurity ions in the plasma, would be analyzed to map radial plasma profiles.

Prof. Barry Stansfield, coordinator of Magnetic Fusion studies at INRS-Énergie.

Materials research and ion-solid interactions.

Basic studies at INRS-Énergie include:

Light ion ranges in fusion materials. Experimental studies of light ion penetration of fusion materials use the Elastic Recoil Detection (ERD) technique pioneered by Prof. Terreault and colleagues in the 1970s. Studies are mainly of the penetration of hydrogen, deuterium, tritium, helium-3 and helium-4 into beryllium, carbon, silicon, carbides and borides. The future emphasis will be on microstructural changes and particle channelling in materials. INRS-Énergie is equipped to carry out depth profiling of tritium in materials.

Hydrogen behaviour in fusion materials. Experiments investigate implantation, saturation and desorption of hydrogen and deuterium implanted in refractory materials with low atomic numbers. Particular attention is paid to the binding energy and state of bonding (chemical, physical traps, bubbles). Investigative methods include laser desorption of hydrogen from materials, electron microscopy and ERD techniques.

Thermomechanical and microstructural properties of coatings and composites. Thermal shock behaviour and microstructure of carbide coatings are studied, in collaboration with the Industrial Materials Institute (IMI) in Boucherville, Québec. Three test limiter heads, coated with titanium carbide at IMI, were exposed to plasma in Tokamak de Varennes last year.

Conditioning and coating Techniques. Plasma-deposited thin film coatings (carbon and boron) are characterized by advanced surface analysis techniques.

Principal scientists in diagnostics development and exploitation and in plasma wall interactions are: Claude Boucher, Brian Gregory, Francois Martin, Royston Painter, Guy Ross, Robert St-Jacques, Barry Stansfield and Bernard Terreault. Prof. Terreault coordinates the plasma wall interactions studies.

Theoretical Studies.

Particular interests include:

- Refined modelling of the atomic physics of plasma processes. Richard Marchand is contributing to development of the Braams B2 plasma edge model.

- A 2D fluid model for the plasma edge in limiter mode including the effect of biasing (Kan Parbhakar).

Further information on magnetic confinement studies: Contact Brian Gregory, Barry Stansfield, or Bernard Terreault (See Contact Data).

New Results: Confinement Research at U. Saskatchewan.

Recent theoretical work at University of Saskatchewan has found interesting correlations between observed confinement behaviour in operating tokamaks, including the Joint European Torus (JET) and others, and theoretical predictions made by Prof. Akira Hirose and coworkers.

Energy and particle confinement performance in research tokamaks has traditionally been anomalous; that is, considerably different from predictions based on plasma theory as presently understood. In particular, two plasma characteristics are poorly understood:

- *anomalous electron thermal diffusivity;* refers to unexpectedly rapid thermal energy loss from a plasma.
- *anomalous inward pinch;* refers to the as yet unexplained drift of ions and electrons toward the centre core of tokamak plasmas, a mechanism often required to simulate a steady-state tokamak discharge.

Hirose and coworkers have developed a theory which may shed some light on these two anomalies.

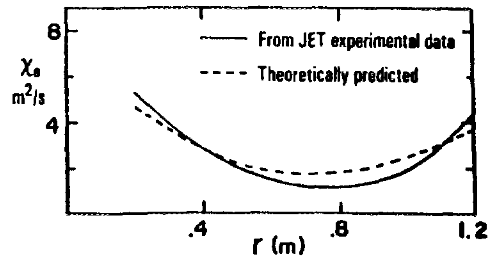
Tokamak plasmas can support many forms of microturbulence, characterized by magnetic and density fluctuations. The theory of Prof. Hirose indicates that:

- a tokamak discharge is linearly unstable against a high frequency (thus short wavelength) electromagnetic drift mode;
- the non-linear consequence of this instability, or microturbulence, has characteristics that may account for the anomalous energy loss and the anomalous inward particle drift.

For the predicted instability, the microturbulence has a characteristic frequency spectrum in the range of hundreds of kilohertz to a few megahertz for typical ohmic discharges. Such high frequency density and concurrent magnetic fluctuations have recently been identified in several tokamaks [1].

The instability is most active in the wavelength regime of $k_{\perp} = \omega_{pe}/c$. The existence of such instabilities has been suspected [2], but not theoretically demonstrated before [3], according to Hirose. The Saskatchewan group used the theory to make estimates for the anomalous electron thermal diffusivity χ_e, and the particle flux in tokamak plasmas, with satisfactory results so far. For example, the accompanying graph shows a comparison of the χ_e predicted versus that inferred from JET data for an ohmic discharge with no auxiliary heating [4]. Agreement can be seen in magnitude and radial profile of χ_e. The predicted electron thermal diffusivity has also been tested against TFTR ohmic data [5] (S. Hiroe, Oak Ridge) with satisfactory agreement.

Some other interesting points of the theory are that the predicted χ_e is proportional to the local safety factor q and to the ion acoustic speed. Therefore, the observed favourable dependence of global energy confinement time on plasma current and ion mass may also be explained by the theory. This work was supported by the Natural Sciences and Engineering Research Council of Canada. Data from other tokamaks will be compared with the theory in the coming months. These results were reported at the 13th IAEA Int. Conf. on Plasma Physics and Controlled Nuclear Fusion Washington, Oct. 2-6.



JET minor radius (m)

[1] V.V. Bulanin et al., Sov. J. Plasma Phys. 15, 147 (1989).
[2] T. Ohkawa, Phys. Lett. 67A, 35 (1978)
[3] Y.Z. Zhang et S.W. Mahajan, Comm. Plasma Phys. Controlled Fusion 21 243 (1988)
[4] D.F. Düchs et al., IAEA Kyoto Conf., vol. 1, p. 325 (1986)
[5] Base de données préparée par D.W. Johnston (PPPL).

More information: Akira Hirose (306) 966-6414, FAX (306) 966-6400.

CFFTP
Canadian Fusion Fuels Technology Project

Points of recent interest arising from CFFTP programs include the following items.

Tritium System for U. Rochester

CFFTP has delivered to University of Rochester, New York, a tritium system for filling microballoon ICF laser targets for laser fusion research. The system, delivered in July this year, will be used to fill plastic or glass microballoon laser targets, diameter about 1 mm, with a 1:1 ratio deuterium-tritium (D-T) gas mixture. The targets will be irradiated by the OMEGA Nd: Glass laser at U. Rochester Laboratory for Laser Energetics. Each microballoon will hold up to five millicuries of tritium as a D-T gas mix at pressures up to 2,200 psia (15,000 kPa). Maximum system tritium inventory is 10,000 Curies. CFFTP was the prime contractor for providing this system; design work was done by

Continues on back page

CCFM
Centre canadien de fusion magnétique

Divertors in Operation on Tokamak de Varennes.

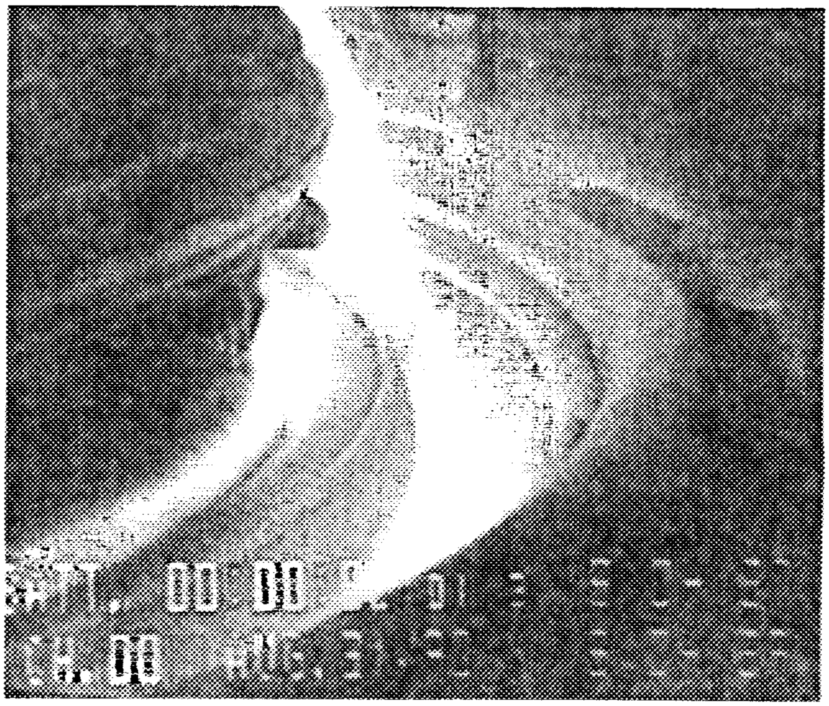
The double-null divertors on Tokamak de Varennes became operational on September 5th, 1990. The Tokamak is now able to sustain repeatable divertor-controlled discharges. As Fusion-Canada goes to press, the Tokamak team is experimenting with divertor operations including plasma biasing through divertor plates and limiters.

When the divertors were first brought into operation, plasma loop voltage (an indicator of plasma impurity content) was reduced to 1.8 volts from the 2.8 volts observed shortly before in limiter mode. The divertors seem to be successful in retaining impurity ions in the closed divertor chambers, thereby significantly reducing particle recycling into the core plasma. By September 6th, divertor discharges of 0.8 seconds had been obtained at currents of 150 kiloamps. Divertor discharges are stable. The fast horizontal position control system, based on a pair of coils inside the vacuum chamber, is also functioning; plasma position is being held within 2 mm for a plasma with a 27 cm minor radius.

By mid-October, it is planned to begin plasma exposure, on the test limiter head, of boronized carbon samples manufactured in Japan and supplied through Yoshi Hirooka of University of California at Los Angeles.

More information: Réal Décoste or Brian Gregory, CCFM (See Contact Data)

Lower divertor in operation on Tokamak de Varennes during divertor-controlled discharges. These photos show the separatrix of the lower divertor, in tokamak discharges # 8754 (above) and # 8755 (below). One sees the plasma edge encircling the inner, lower divertor coil. In these video-processed images, the null point can just be discerned. The three divertor coils are clearly seen. *Images by Will Zuzak, INRS-Énergie.*



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Wardrop Engineering (Mississauga, Ont.) under CFFTP direction.

More information: Allan Meikle, CFFTP (416) 855-4724 (see Contact Data).

Technology Transfer

The position of Manager-Technology Transfer Projects was created at CFFTP, as part of CFFTP strategy to further encourage industry participation in building the fusion technology infrastructure in Canada. Objectives of CFFTP's technology transfer effort include:

- Promoting use of fusion technologies in non-fusion applications.
- Enhancing the two-way technical and scientific exchange between fusion and non-fusion communities.
- Using non-fusion applications to test and refine technologies for fusion use.

The approach recognizes that full application of fusion technologies in commercial fusion power plants will not occur for some time. Successful employment of fusion technologies in non-fusion applications could expand the development of industrial capability in fusion technologies in the nearer term.

More information: Nick Markettos, Manager Technology Transfer Projects, CFFTP (416) 855-4703 (see Contact Data)

CFFTP Annual Report

The CFFTP Annual Report for 1989/90 was released in August; it is available on request. The Report summarizes progress in CFFTP technical programs: Blanket and First Wall; Fusion Fuels Systems; Safety and Environment; ITER/NET Design and Engineering; Technology Applications. A listing of CFFTP scientific and technical papers is provided.

For copies of the Annual Report, contact the CFFTP Information Coordinator (See Contact Data).

National Fusion Program

Director, *Dr. David P. Jackson*

The National Fusion Program (NFP) coordinates and supports fusion development in Canada. NFP was established to develop Canadian fusion capability, in industry and in research and development centres. NFP develops international collaboration agreements, and assists Canadian fusion centres to participate in foreign and international projects.

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